Communication Theory (5ETB0)
Module 2.2

Alex Alvarado
a.alvarado@tue.nl

Information and Communication Theory Lab
Signal Processing Systems Group
Department of Electrical Engineering
Eindhoven University of Technology, The Netherlands

www.tue.nl/ictlab/

Module 2.2

Presentation Outline

The General Communication Problem

Elements in a communications system

$$\text{Source} \xrightarrow{u(t)} \text{Transmitter} \xrightarrow{s(t)} \text{Channel} \xrightarrow{r(t)} \text{Receiver} \xrightarrow{v(t)} \text{Destination}$$

- **Source**: Emits a real-valued waveform which contains the information to be transmitted (mic., sensor, etc.)
- **Transmitter**: Converts the source waveform into the waveform that will be sent through the channel (distance)
- **Channel**: Accepts a waveform and it gives as output another waveform (continuous- or discrete-input)
- **Receiver**: Tries to reconstruct $u(t)$ based on $r(t)$ (guessing)

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Presentation Outline

White Gaussian Noise

White Noise Waveform

A white noise waveform $n_w(t)$ is generated by the random process $N_w(t)$, which is (i) zero-mean, (ii) stationary, (iii) white, and (iv) Gaussian.

(i) Zero mean: $E[N_w(t)] = 0$

(ii) Stationary:

$$R_{N_w}(t,s) \triangleq E[N_w(t)N_w(s)] = \frac{N_0}{2}\delta(t-s),$$

(iii) White:

$$S_{N_w}(f) = \frac{N_0}{2}\left[\frac{W}{Hz}\right], \text{ for } -\infty < f < \infty,$$

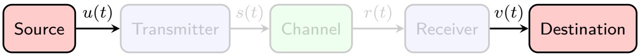
where $S_{N_w}(f)$ is the PSD, i.e, the FT of the autocorr. function.

(iv) Gaussian: The random vector of samples

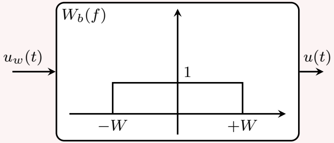
$$\underline{n} = (N_w(t_1), N_w(t_2), \ldots, N_w(t_N))$$

is jointly Gaussian for any finite set of sampling instants $\{t_1, t_2, \ldots, t_N\}$

A Waveform Source



Baseband Gaussian Source

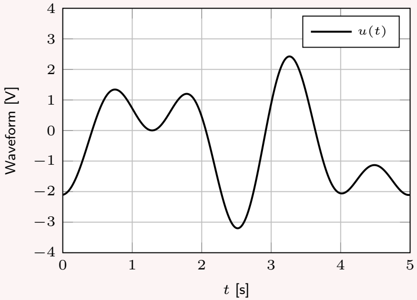


$$u(t) = u_w(t) * w_b(t)$$

Limitations:

- Not the best model. Analog sources typically not white, not baseband, not Gaussian
- Worst source we can have (in terms of compression)

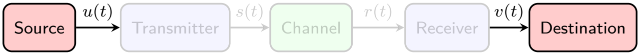
Example source waveform $u(t)$



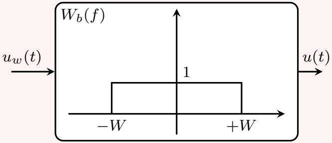
Bandwidth is $W = 1$ Hz.

How different would it be if $W = 10$ Hz?

A Waveform Source



Baseband Gaussian Source



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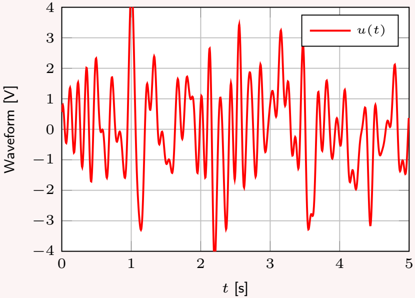
Example source waveform $u(t)$

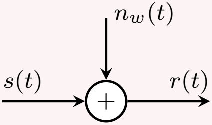


Bandwidth is $W = 1$ Hz.

How different would it be if $W = 10$ Hz?

Three Waveform Channels (1/2)

(1) Wideband AWGN Channel

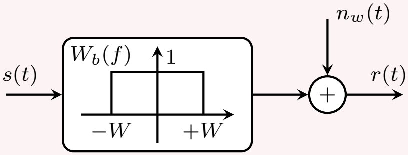


Wideband AWGN channel

$$r(t) = s(t) + n_w(t)$$

Why is this not realistic?

(2) Baseband AWGN Channel



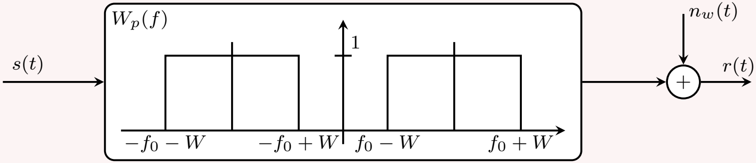
Baseband AWGN channel

$$r(t) = s(t) * w_b(t) + n_w(t)$$

Good model for copper cables

Three Waveform Channels (2/2)

(3) Passband AWGN Channel



Passband AWGN channel

$$r(t) = s(t) * w_p(t) + n_w(t),$$

Passband transmission with frequency determined by the channel

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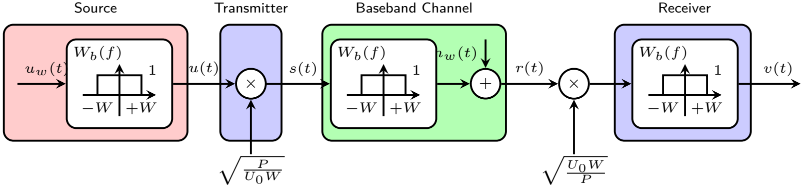
Presentation Outline

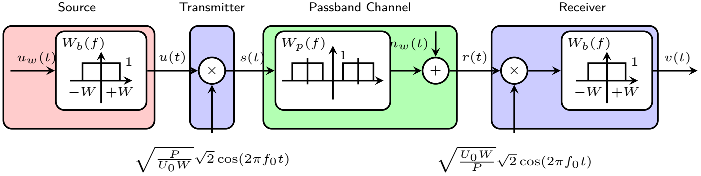
Baseband Transmission



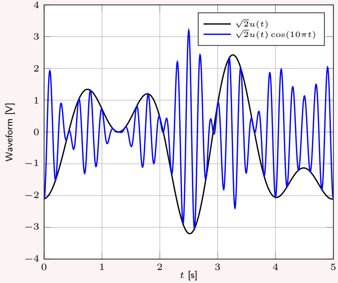
Baseband Transmission

- **Definition:** *Instantaneous power is $s^2(t)$. Average power is $E[S^2(t)]$. Average transmit power P is limited, and thus, $E[S^2(t)] \leq P$.*
- **Power distortion**: $d(t) \triangleq v(t) - u(t) = \sqrt{U_0 W/P} \cdot n_w(t) * w_b(t)$
- **Variance distortion**: $E[D^2(t)] = \frac{U_0 W}{P} \frac{N_0}{2} 2W = U_0 W \frac{N_0 W}{P}$
- **Mean squared error distortion**: $D = E[D^2(t)]$
- **Source signal-to-distortion ratio**: SDR $\triangleq \frac{E[U^2(t)]}{E[D^2(t)]} = \frac{P}{N_0 W} = \text{SNR}_b$, where SNR_b is the baseband channel **signal-to-noise ratio**.

Passband Transmission (DSB-SC)



Input waveform



SDR for DSB-SC

- The source SDR (signal to distortion ratio)

$$\frac{E[U^2(t)]}{E[D^2(t)]} = \frac{P}{N_0 W}$$

  which is equal to SNR_b.

- *The SDR is the same we found for base-band Tx!*

Pros and Cons of Analog Transmission

Pros:

- Easy to implemente using analog electronics
- Graceful degradation
- Easy multiplexing using frequency-division multiplexing (FDMA)

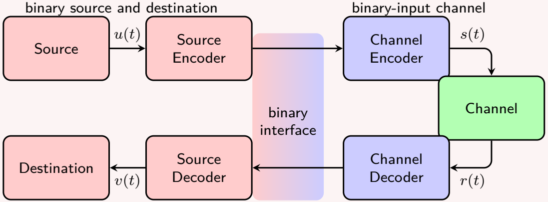
Cons:

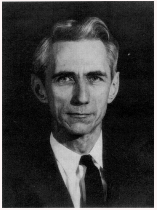
- Not flexible with channel BW requirement
- SNR decrease in each hop (relay)
- Encryption and compression very difficult

Digital Communication

Two key ideas from Shannon (1948)

- All sources can be represented by binary sequences
- Source and channel processing can be separated





Claude Shannon—Father of the Information Age
Two videos in Canvas:
https://youtu.be/z2Whj_nL-x8
https://youtu.be/E3OldEtfBrE

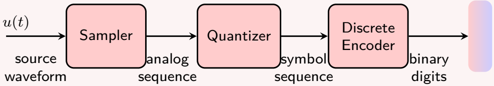
Digital Communication

The Pros of Digital Communication

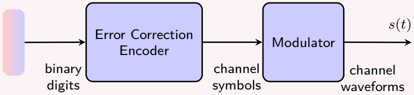
- Cheap, reliable and miniaturized digital hardware
- Simple quality control (error rates, detection, correction)
- Simplified system development thanks to binary interface
- No performance loss by source and channel separation
- Simplified networking thanks to binary interface
- Efficient utilization of resources (source coding)

Source and Channel Processing

Dividing Source and Channel Processing



Dividing source processing at the transmit side into sampling, quantizing, and discrete encoding



Dividing channel processing at the transmit side into error correction encoding, and modulation

Source processing and error correction not treated in this course, but in

- 5XSE0 Information Theory (Q3, BSc)
- 5LSF0 Applications of information theory (Q4, MSc)
- In the invited lecture

Summary Module 2.2

Take Home Messages

- Communication problem: a guessing problem
- Analog sources, white Gaussian noise
- Baseband Gaussian source
- Three channels: Wideband, Baseband and Passband AWGN
- Digital vs. Analog? Digital!

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